The Case for a Super Neutrino Beam

Milind Diwan
Brookhaven National Laboratory
February 28, 2005

Physics and accelerator working group based at BNL.

Frascati Physics Series
Heavy Quarks and Leptons – San Juan, Puerto Rico, June 1 - June 5, 2004

The Case for a Super Neutrino Beam

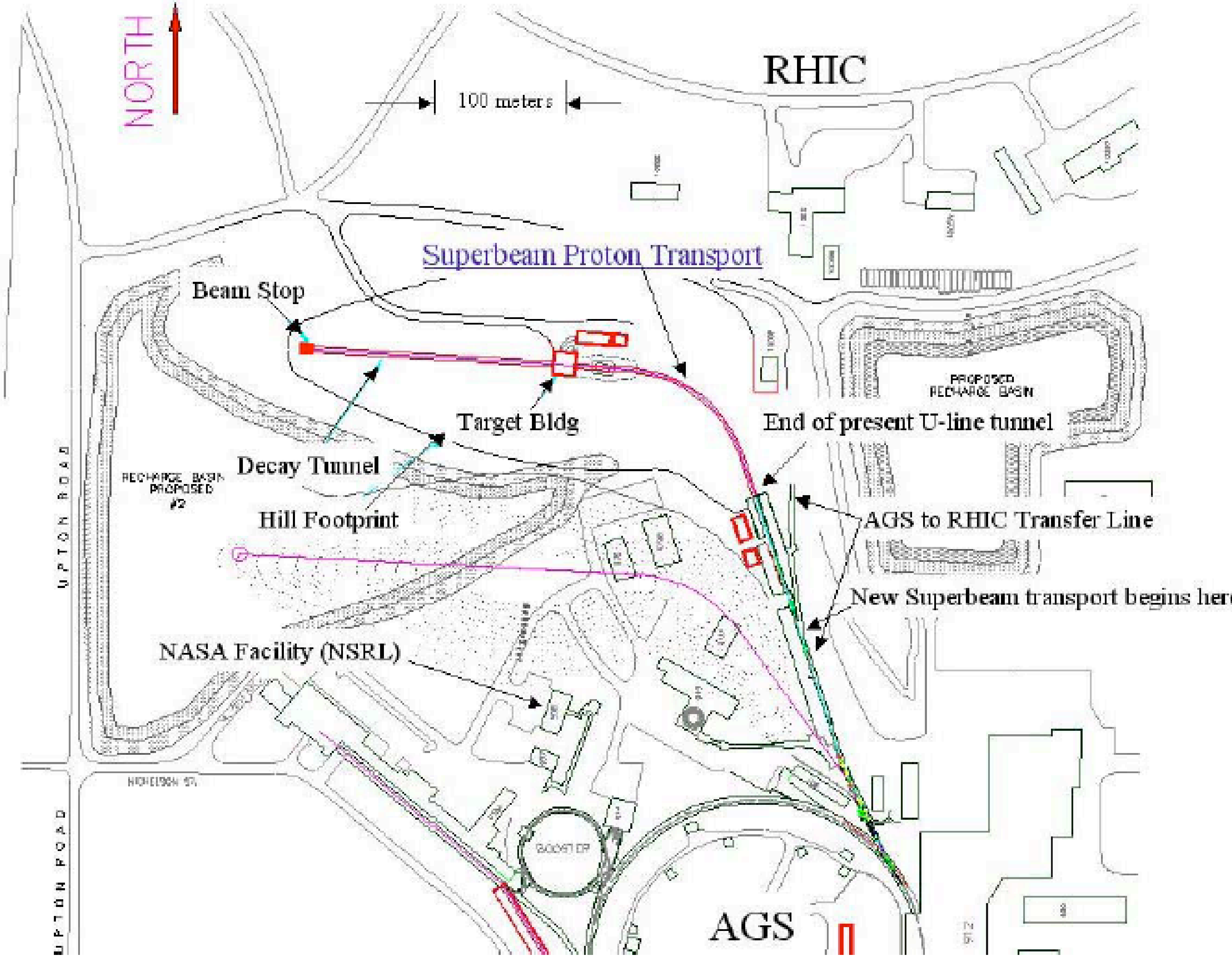
Milind V. Diwan
Brookhaven National Laboratory

ABSTRACT

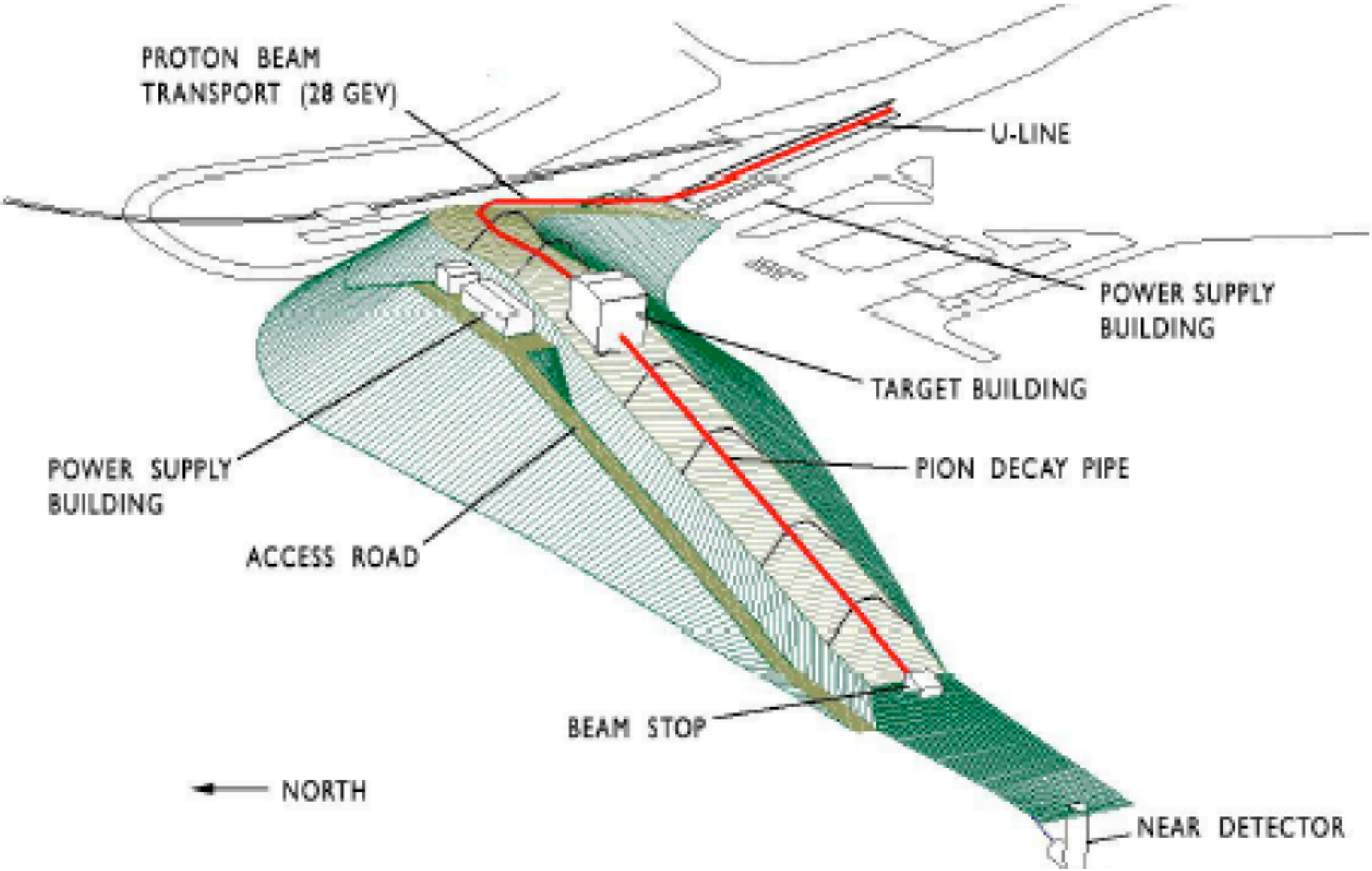
In this paper I will discuss how an intense beam of high energy neutrinos produced with conventional technology could be used to further our understanding of neutrino masses and mixings. I will describe the possibility of building such a beam at existing U.S. laboratories. Such a project couples naturally to a large (> 100 kT) multipurpose detector in a new deep underground laboratory. I will discuss the requirements for such a detector. Since the number of sites for both an accelerator laboratory and a deep laboratory are limited, I will discuss how the choice of baseline affects the physics sensitivities, the practical issues of beam construction, and event rates.

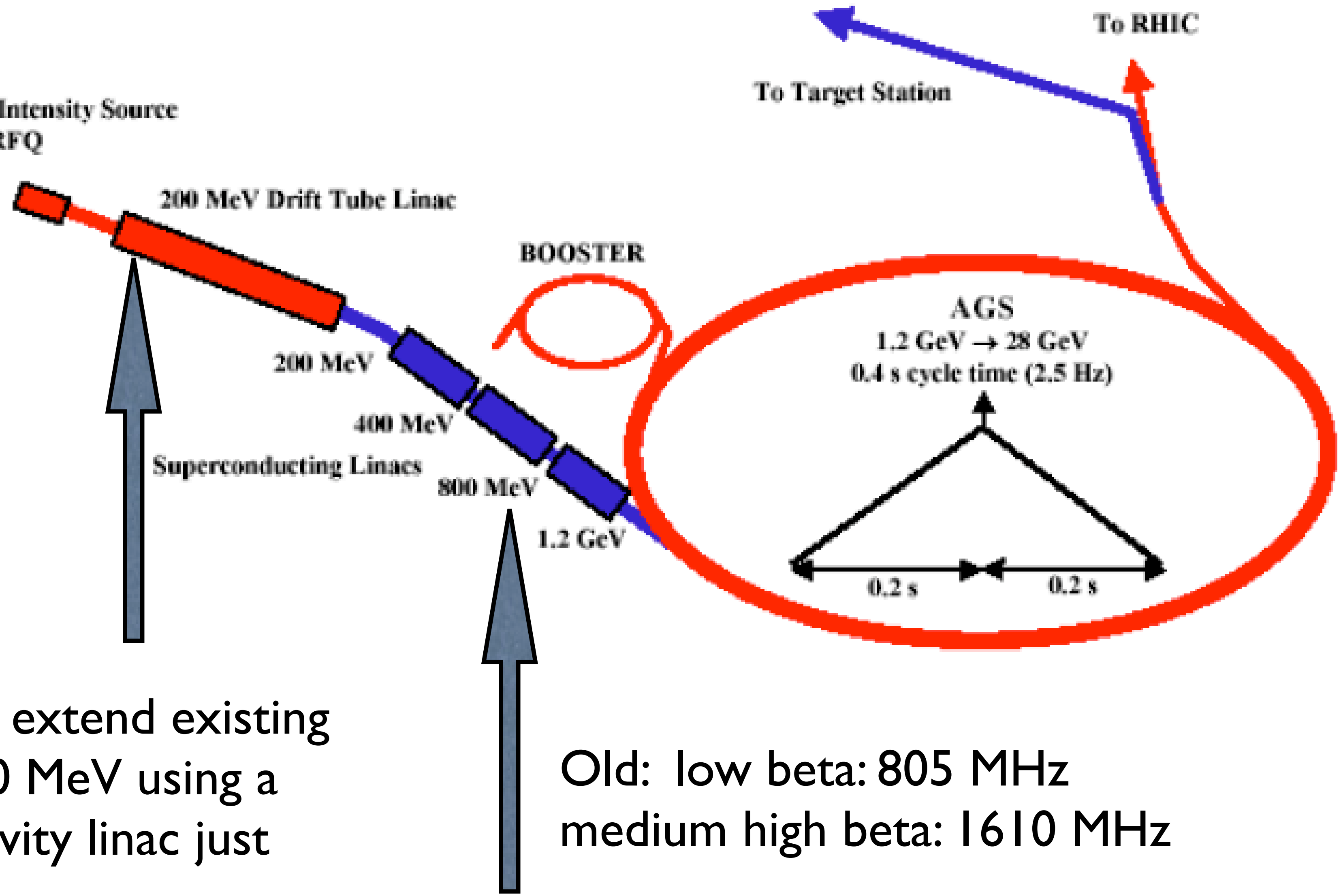
Update on AGS based Super Neutrino beam

- conceptual design document BNL-73210-2004-IR. (sent to DOE Oct ‘04)
- http://raparia.sns.bnl.gov/nwd_ad
- Working on: Redesigned beam facility: more compact, now possible to make decay pipe longer.
- Working on: Completely new design for injector LINAC: cheaper and faster to build.



NORTH
100 meters
RHIC
Superbeam Proton Transport
Beam Stop
Target Bldg
Decay Tunnel
Hill Footprint
End of present U-line tunnel
AGS to RHIC Transfer Line
New Superbeam transport begins here
NASA Facility (NSRL)
PROPOSED RECHARGE BASIN
RECHARGE BASIN PROPOSED #2
UPTON ROAD
UPTON ROAD
BOOSTER
AGS


PROTON BEAM
TRANSPORT (28 GEV)
U-LINE
POWER SUPPLY
BUILDING
TARGET BUILDING
PION DECAY PIPE
POWER SUPPLY
BUILDING
ACCESS ROAD
BEAM STOP
NORTH
NEAR DETECTOR



New idea: extend existing RTL to 400 MeV using a coupled cavity linac just like FNAL

Old: low beta: 805 MHz
medium high beta: 1610 MHz

New idea: after 400 MeV use 805 MHz all the way to ~1.4 GeV.
Use SNS design and get to higher energy

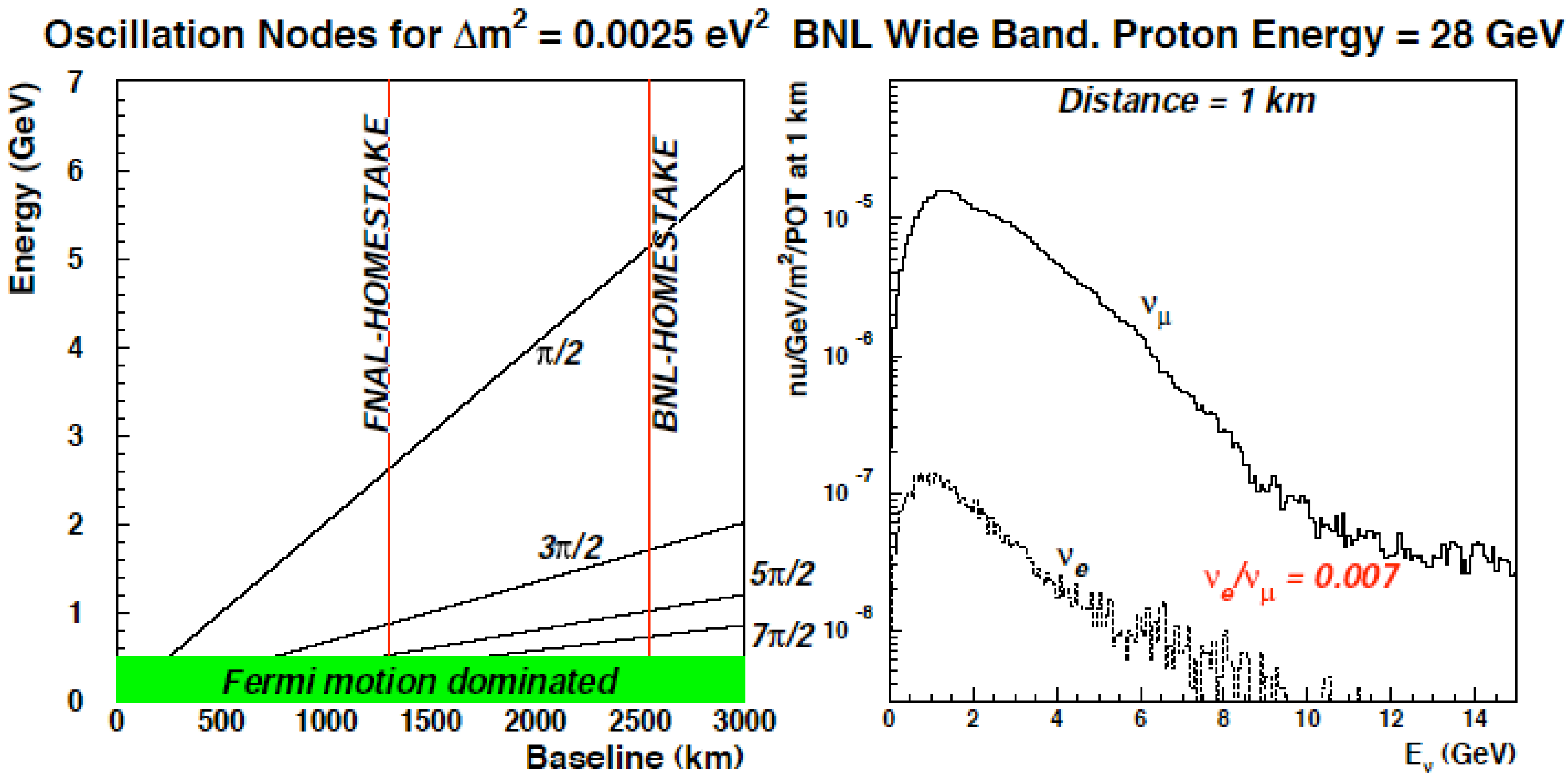
Important technical issues:
1 ms pulse in LINAC
Transition losses in AGS

Cost Estimate of the AGS Super Neutrino Beam Facility

Construction Phase - Direct FY04 Dollars

1.0 AGS Super Neutrino Beam Facility	EDIA	M&S	Labor	Total
1.1 The Linac System	**6,879,116**	**98,556,970**	**16,783,762**	**122,219,848**
1.1.1 Front End and RT Linac Upgrade	313,000	2,383,000	856,000	**3,552,000**
1.1.2 SCL Accelerating Cavity System	954,240	22,254,200	11,040,000	**34,248,440**
1.1.3 SCL RF Source	3,620,988	51,668,800	402,332	**55,692,120**
1.1.4 SCL Cryogenic System	370,000	13,700,000	2,200,000	**16,270,000**
1.1.5 SCL Vacuum System	641,598	3,474,570	1,148,378	**5,264,546**
1.1.6 SCL Instrumentation	460,957	1,390,400	409,061	**2,260,418**
1.1.7 SCL Magnet and Power Supply	518,332	3,686,000	727,991	**4,932,324**
1.2 The AGS Upgrade	**10,496,245**	**53,619,159**	**6,472,590**	**70,587,994**
1.2.1 AGS Main Magnet Power Supply	503,959	28,200,000	1,342,337	**30,046,296**
1.2.2 AGS RF System Upgrade	6,082,625	9,850,000	675,847	**16,608,472**
1.2.3 AGS Injection/Extraction	644,000	6,437,066	1,668,330	**8,749,396**
1.2.4 Beam Transport to Target	1,636,771	7,852,241	2,637,290	**12,126,302**
1.2.5 Control System	1,628,890	1,279,852	148,786	**3,057,528**
1.3 The Target and Horn System	**664,742**	**3,417,152**	**1,208,338**	**5,290,232**
1.3.1 The Target System	127,008	229,284	50,130	**406,422**
1.3.2 The Horn System	454,524	2,358,568	656,224	**3,469,316**
1.3.3 Shielding and Remote Handling	83,210	809,300	125,300	**1,017,810**
1.3.4 Target & Horn Physics Support	0	20,000	376,684	**396,684**
1.4 The Conventional Facility	**7,550,300**	**60,090,300**	**1,210,700**	**68,851,300**
1.4.1 Linac Tunnel/Klystron Gallery	2,253,000	11,529,000	230,000	**14,012,000**
1.4.2 AGS Power Supply Building	2,024,000	13,347,000	432,000	**15,803,000**
1.4.3 Beam Transport and Target Area	1,674,300	25,091,000	172,500	**26,937,800**
1.4.4 The Decay Tunnel and Beam Stop	184,000	1,225,300	115,200	**1,524,500**
1.4.5 Site Utilities & Roads	1,088,000	6,820,000	140,000	**8,048,000**
1.4.6 Modifications for AGS RF System	327,000	2,078,000	121,000	**2,526,000**
1.5 ES&H	**104,652**	**275,211**	**437,355**	**817,218**
1.5.1 ES&H	20,000	105,000	270,000	**395,000**
1.5.2 Access Controls.	84,652	170,211	167,355	**422,218**
1.6 Project Support	**1,148,681**	**384,109**	**4,096,963**	**5,629,753**
1.6.1 Project Management	0	100,000	1,178,000	**1,278,000**
1.6.2 Technical Support	1,148,681	214,109	2,146,963	**3,509,753**
1.6.3 Project Controls	0	70,000	772,000	**842,000**
AGS Super Neutrino Beam Facility Project Total	**26,843,736**	**216,342,901**	**30,209,709**	**273,396,345**

Back to Very Long Baselines



Use same spectrum to study both baselines for this study. Comment on useful spectrum changes. Use 500 kT for both baselines with same performance.

Simple rules

- Multiples nodes important for precision and new physics.
- Long distances separate CP and matter effects.
- Need 2500 kT*MW*(10^7 sec) for measuring CP (regardless of distance and value of θ_{13})
- For CP violation study NO conventional beam experiment can get below $\sin^2 2\theta_{13} \sim 0.01$

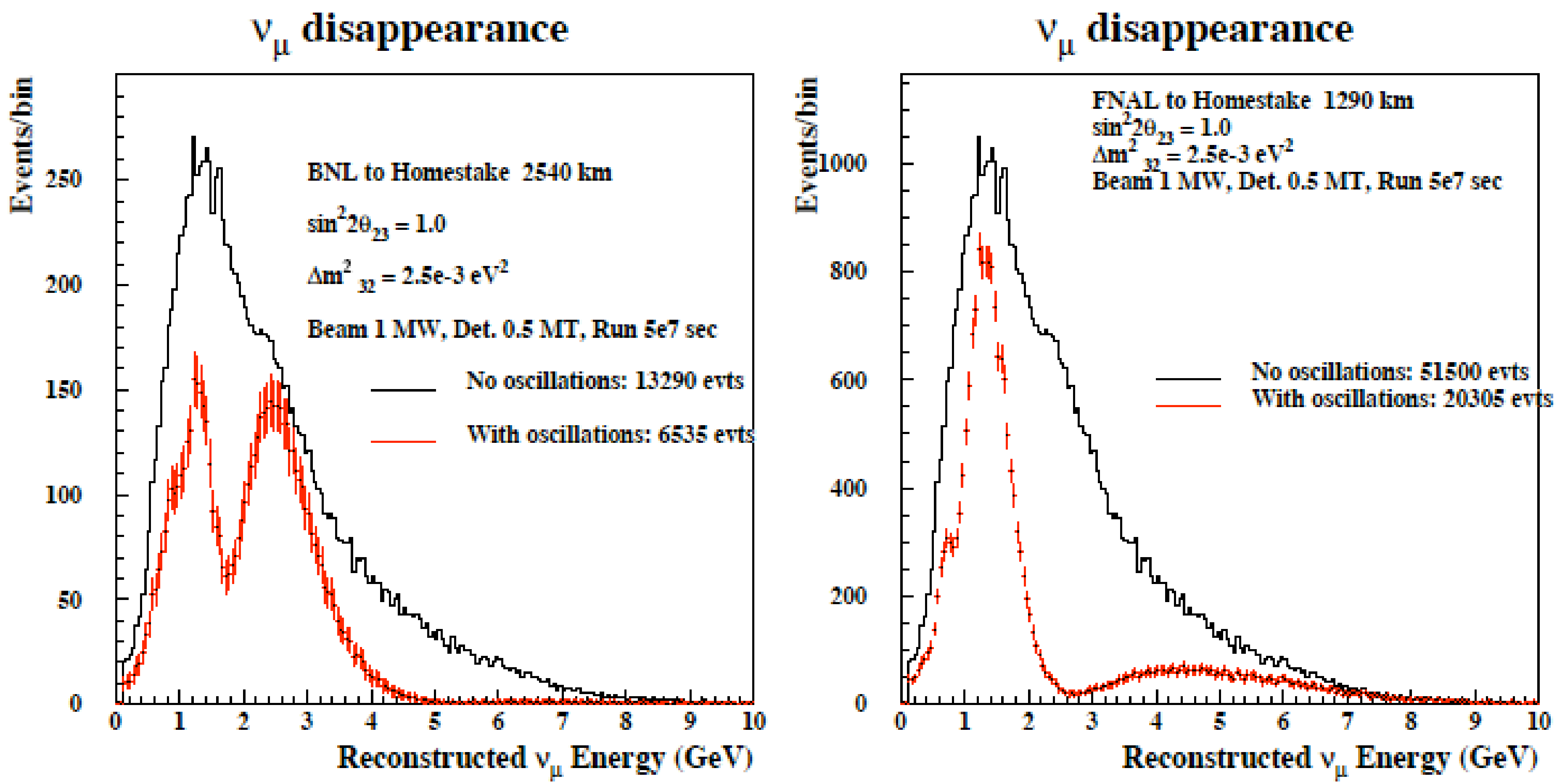


Figure 2: *Simulated spectrum of detected muon neutrinos for 1 MW beam and 500 kT detector exposed for* 5×10^7 *sec. Left side is for baseline of 2540 km, right side for baseline of 1290 km. The oscillation parameters assumed are shown in the figure. Only clean single muon events are assumed to be used for this measurement (see text).*

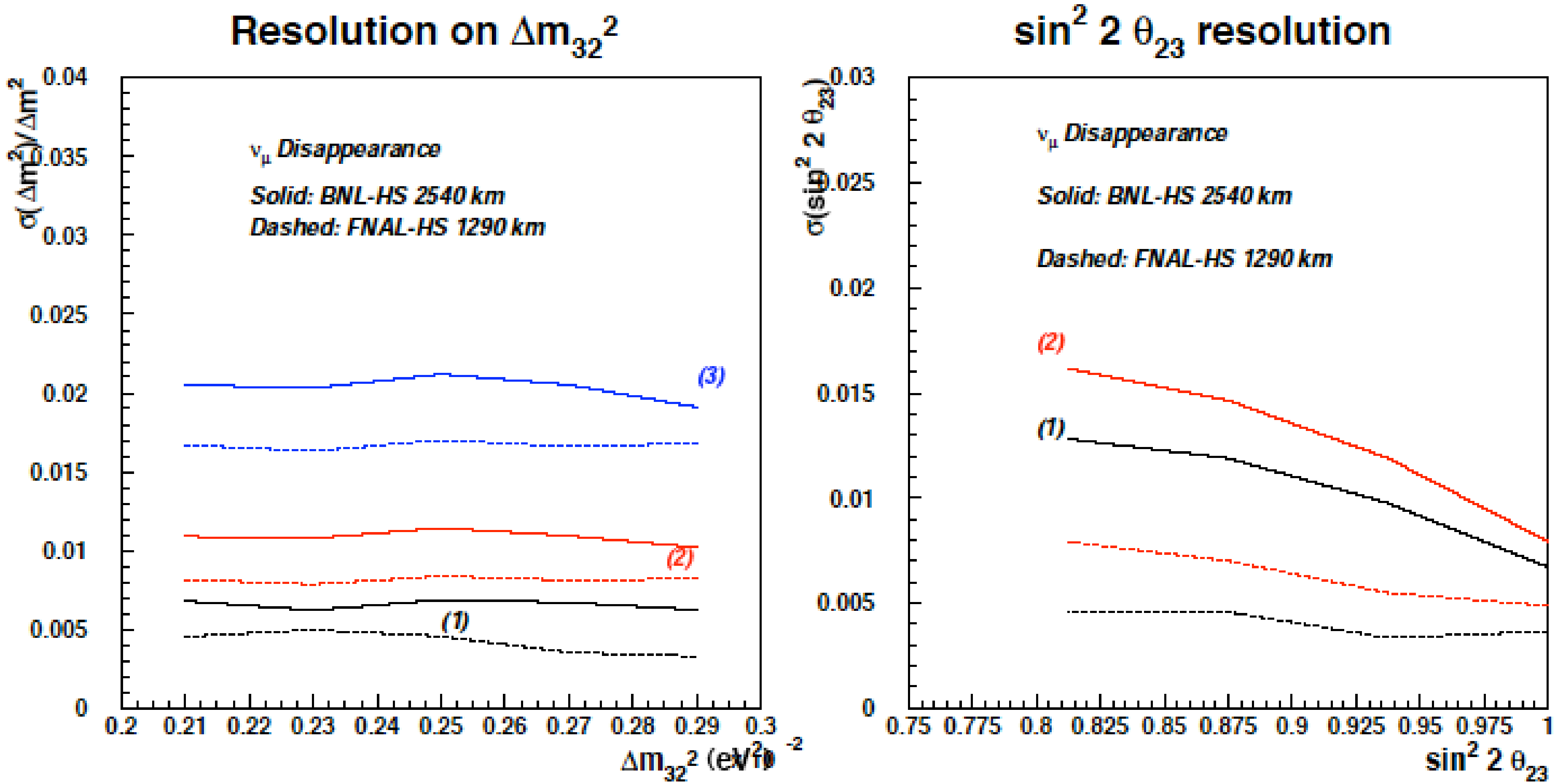
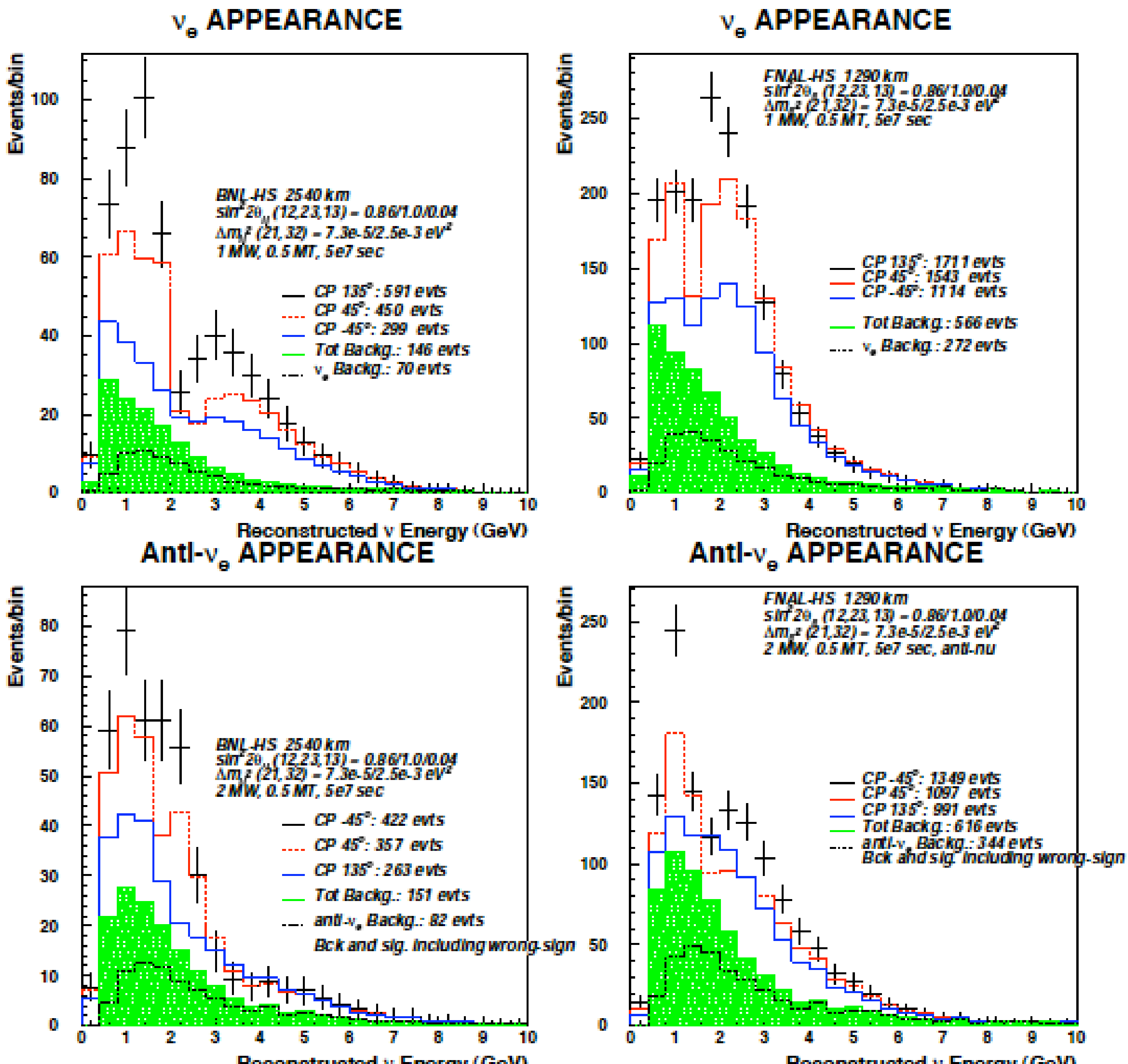


Figure 3: *1 sigma resolutions on* Δm^2_{32} *(left) and* $\sin^2 2\theta_{23}$ *(right) expected after analysis of the oscillation spectra from Figure 2. The solid curves are for BNL-HS 2540 km baseline, and the dashed are for FNAL-HS 1290 km baseline. The curves labeled 1 and 2 correspond to statistics only and statistics and systematics, respectively (similarly for dashed curves of the same color). The curve labeled (3) on the left has an additional contribution of* 1% *systematic error on the global energy scale.*



ν_e APPEARANCE
Events/bin
BNL-HS 2540 km
$\sin^2 2\theta_{ij}$ (12,23,13) = 0.86/1.0/0.04
Δm^2_{ij} (21,32) = 7.3e-5/2.5e-3 eV^2
1 MW, 0.5 MT, 5e7 sec
CP 135°: 591 evts
CP 45°: 450 evts
CP -45°: 299 evts
Tot Backg.: 146 evts
ν_e Backg.: 70 evts
Reconstructed ν Energy (GeV)
ν_e APPEARANCE
Events/bin
FNAL-HS 1290 km
$\sin^2 2\theta_{ij}$ (12,23,13) = 0.86/1.0/0.04
Δm^2_{ij} (21,32) = 7.3e-5/2.5e-3 eV^2
1 MW, 0.5 MT, 5e7 sec
CP 135°: 1711 evts
CP 45°: 1543 evts
CP -45°: 1114 evts
Tot Backg.: 566 evts
ν_e Backg.: 272 evts
Reconstructed ν Energy (GeV)
Anti-ν_e APPEARANCE
Events/bin
BNL-HS 2540 km
$\sin^2 2\theta_{ij}$ (12,23,13) = 0.86/1.0/0.04
Δm^2_{ij} (21,32) = 7.3e-5/2.5e-3 eV^2
2 MW, 0.5 MT, 5e7 sec
CP -45°: 422 evts
CP 45°: 357 evts
CP 135°: 263 evts
Tot Backg.: 151 evts
anti-ν_e Backg.: 82 evts
Bck and sig. including wrong-sign
Reconstructed ν Energy (GeV)
Anti-ν_e APPEARANCE
Events/bin
FNAL-HS 1290 km
$\sin^2 2\theta_{ij}$ (12,23,13) = 0.86/1.0/0.04
Δm^2_{ij} (21,32) = 7.3e-5/2.5e-3 eV^2
2 MW, 0.5 MT, 5e7 sec, anti-nu
CP -45°: 1349 evts
CP 45°: 1097 evts
CP 135°: 991 evts
Tot Backg.: 616 evts
anti-ν_e Backg.: 344 evts
Bck and sig. including wrong-sign
Reconstructed ν Energy (GeV)

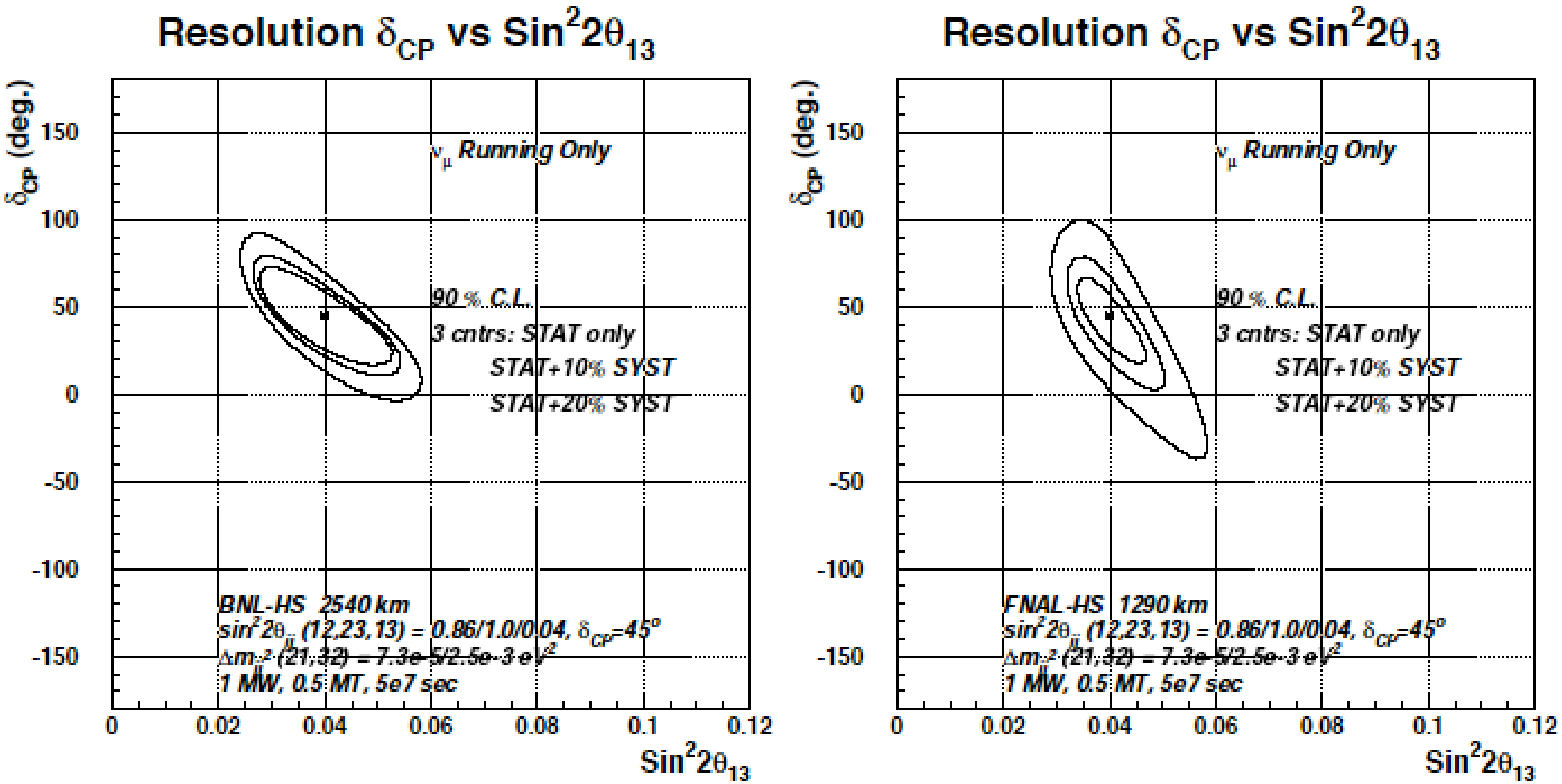


Figure 6: *90% confidence level error contours in* $\sin^2 2\theta_{13}$ *versus* δ_{CP} *for statistical and systematic errors with neutrino data alone. Left is for BNL-HS and right is for FNAL-HS. The test point used here is* $\sin^2 2\theta_{13} = 0.04$ *and* $\delta_{CP} = 45^o$. $\Delta m^2_{32} = 0.0025\ eV^2$, *and* $\Delta m^2_{21} = 7.3 \times 10^{-5}\ eV^2$. *The values of* $\sin^2 2\theta_{12}$ *and* $\sin^2 2\theta_{23}$ *are set to 0.86, 1.0, respectively.*

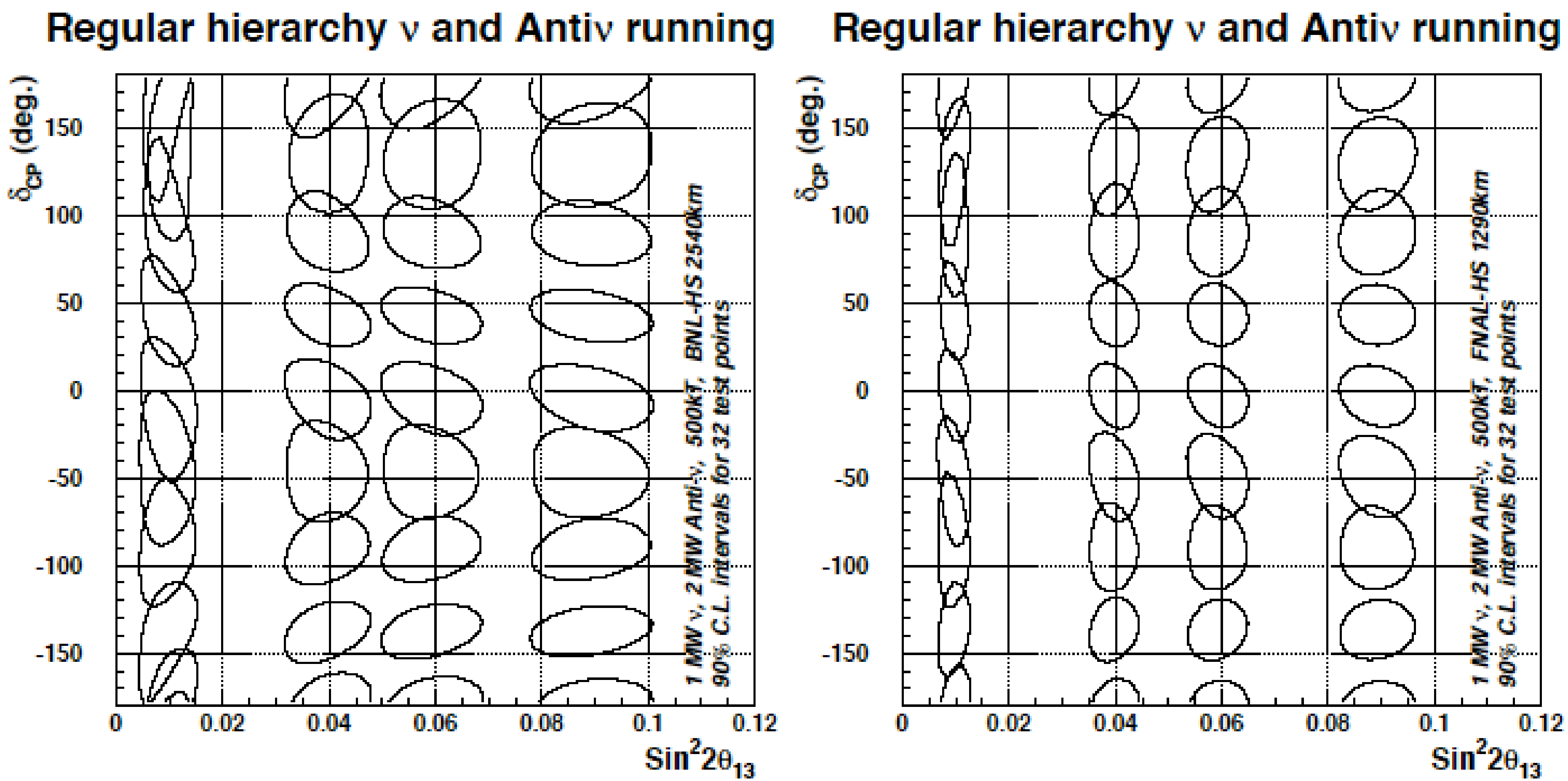


Figure 7: *90% confidence level error contours in* $\sin^2 2\theta_{13}$ *versus* δ_{CP} *for statistical and systematic errors for 32 test points. This simulation is for combining both neutrino and anti-neutrino data. Left is for BNL-HS and right is for FNAL-HS. We assume 10% systematic errors for this plot.*

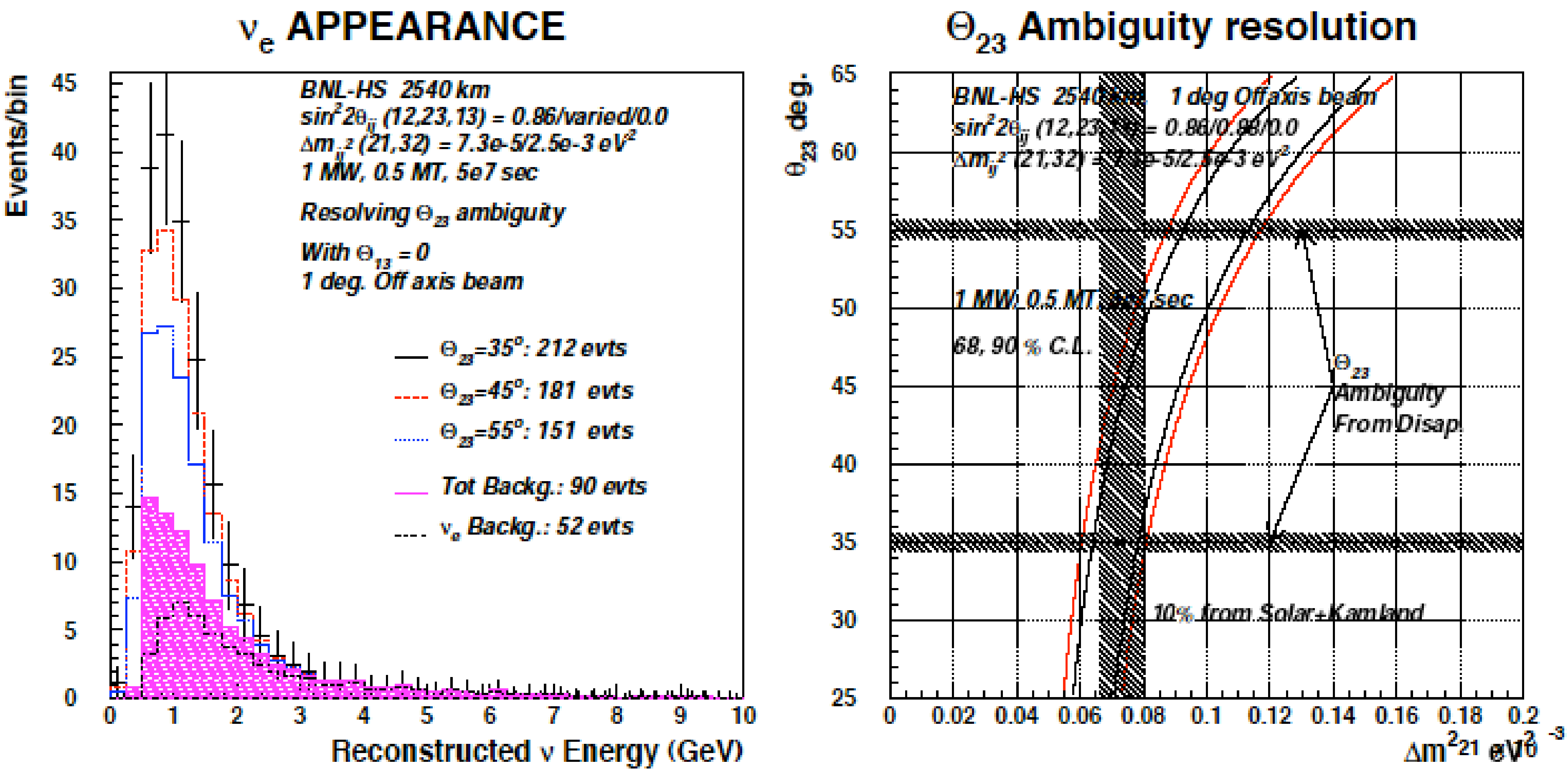


Figure 8: *Expected spectrum of electron neutrinos (left) for* $\theta_{13} = 0$ *and other assumed parameters indicated in the figure. The right hand side shows the resolution of the* $\theta_{23} \to \pi/2 - \theta_{23}$ *ambiguity using the measurement of* $\sin^2 2\theta_{23}$ *from disappearance and assuming a 10% measurement of* Δm^2_{21} *from KAMLAND. The area between the curves is allowed by the appearance spectrum (left) for* $\theta_{23} = 35^o$.

Stage 1 ?

- What physics if we put some constraints ?
- Accelerator upgrade is possible in 5 years.
- Construction of 200 kT possible in 5 years ?
- Assume 2 10^7 sec of initial running.
- Is this good enough to achieve something ?

Event Rates(neutrino running only

Event type	2540km/ 500kt/5yrs	1290km/ 500kt/5yrs	2540km/ 250kt/2yrs	1290km/ 250kt/2yrs
CC total	52000	201600	10400	40248
NC total	18000	69784	3600	13932
CC with cuts no osc	13290	51500	2658	10300
CC with cuts with osc	6535	20305	1307	4061
numu->nue signal	450	1543	90	308
numu->nue backg	146	566	29	113

Sin2th13=0.04 thcp=45deg

Detector

- Requirements: Very ambitious !
  - 500 kTons fiducial mass for both Proton decay and neutrino astro-physics and neutrino beam physics.
  - ~10 % energy resolution on quasielastic events
  - Muon/electron discrimination at <1%
  - 1, 2, 3 track event separation
  - Showering NC event rejection at factor of ~15
  - Low threshold (~~~10-15~~ 5 MeV) for supernova search
  - Part of the detector could have lower threshold for solar neutrino detection.
  - Time resolution of ~few ns for pattern recognition and background reduction.

Conclusions.

- Shorter baseline better for measuring mixing angles.
- CP phase measurement statistically indep of distance, but better at longer distance because systematic errors less important.
- With longer distance can get CP phase with neutrino running alone.
- Longer distance better for solar effect and resolving th23 ambiguity.
- Could probably justify initial smaller det. and less running for a quicker start.
- Eventually have to couple to DUSEL 1 MT det...... How do we start Detector R&D ?